Evolution of Nonlinear Internal Waves In China Seas

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LONG-TERM GOAL

To study nonlinear ocean internal wave processes in the East and South China Seas, and Yellow Sea by using satellite synthetic aperture radar (SAR) imagery, in-situ data, and numerical models.

OBJECTIVES

To understand the environmental effects (e.g. bottom topography, shoaling, mixing, and current/shear) on nonlinear internal wave generation, evolution, and dissipation. Of particular interest are the generation of elevation internal waves by upwelling northeast of Taiwan caused by the intrusion of Kuroshio on the continental shelf. The generation of mode-two internal solitons in the South China Sea is also a very important issue. The challenge is to collect in-situ measurements simultaneous with satellite coverage and to synthesize all data by numerical models.

APPROACH

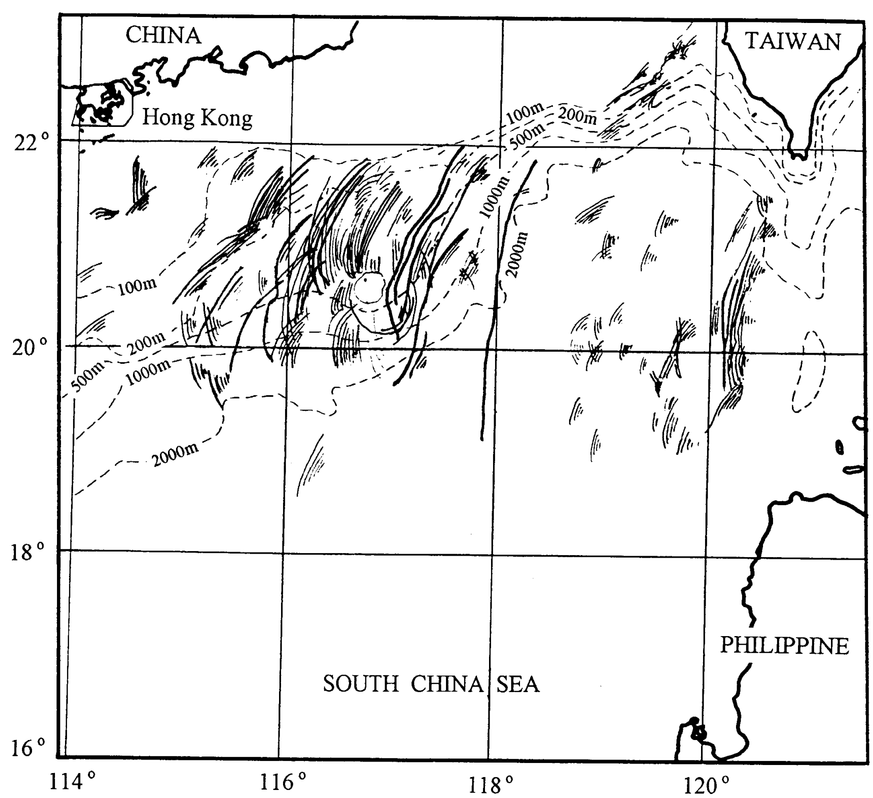
Synthetic Aperture Radar (SAR) images from ERS-1/2 and RADARSAT have been used to study the characteristics of internal waves northeast and south of Taiwan in the East China Sea, South China Sea, and in the Yellow Sea in conjunction with moorings and field measurements. The numerical simulations of internal wave evolution on the continental shelf have been performed and compare with SAR observations, especially for the evolution of nonlinear waves and the disintegration of solitons into wave packets. A parametric study for various environmental conditions to assess the nonlinear effects such as bottom topography (across critical depth), shoaling, stratification, and dissipation has been conducted. The generation and evolution of internal waves (elevation versus depression, and mode-one versus mode-two), and wave-wave interaction will be studied using satellite data in conjunction with in-situ data from the field experiments. All data will be synthesized/integrated by using numerical models.

WORK COMPLETED

Based on the SAR images and hydrographic data, internal waves of elevation have been identified in shallow water due to a thicker mixed layer as compared with the bottom layer on the continental shelf (Liang et al., 1995). The generation mechanisms including the influences of the tide and the Kuroshio intrusion across the continental shelf for the formations of both elevation and depression internal waves under various ocean conditions have been investigated (Hsu et al., 1999). The effects of water depth on the evolution of solitons and wave packets are modeled by nonlinear Kortweg-deVries (KdV) type equation (Liu, 1988) and linked to satellite image observations. A parametric study for various environmental conditions have been carried out by the numerical simulations to demonstrate and to assess the nonlinear effects such as bottom topography, shoaling (across critical depth), dissipation/mixing, and wave-wave interaction on internal wave evolution.

In the South China Sea, both depression and elevation waves were observed in the SAR images during the summer and spring seasons at the same location, respectively (Liu et al., 1998). The internal wave packets with more than 15 solitons were observed and measured by the ERS-1 SAR and the thermistor chain from a research ship in the Yellow Sea. Based on the SAR images, these many solitons may be caused by the wave-wave interaction (Hsu et al., 1998). The comparisons of the characteristics of the internal wave evolution in the US East coast water, in the East and South China Seas, and Yellow Sea have been identified. Recently, the internal wave distribution maps have been compiled from more than three hundreds of ERS-1/2, RADARSAT and Space Shuttle SAR images in the East and South China Seas (Figure 1) and Yellow Sea from 1993 to 1998 by Hsu et al. (1999).

The internal wave distribution map in the northeast of South China Sea is shown in Figure 1.



Based on the internal wave distribution map, most of internal waves in the northeast part of South China Sea are propagating westward. The wave crest can be as long as 200 km with amplitude of 100 m, due to strong current from the Kuroshio branching out into the South China Sea (Liu et al., 1998). From the observations at drilling rigs near DongSha Island by Amoco Production Co. (Bole et al., 1994), the solitons may be generated in a 4 km wide channel between Batan and Sabtang islands in Luzon Strait. The sill between Batan and Sabtang islands is like a saddle point. The proposed generation mechanism is similar to the lee wave formation from a shallow topography in the Sulu Sea

(Apel et. al., 1985; Liu et. al, 1985). The disturbance of mixed area with downward displacement of the pycnocline is then driven by the semi-diurnal tide and evolves into a rank-ordered wave packet. But, the detailed wave generation mechanisms and locations are still not well understood since there are no measurements near the sources.

Historical field data collected by Amoco Co. from drilling rigs have been studied and compared with new field data. Field data have been collected by routine expeditions from Taiwan ocean research ships (R/V-1 and 3) under newly funded Kuroshio Upstream Dynamics Experiment (KUDEX). For the field test, it is designed to deploy several moorings in the internal wave active area, with temperature, salinity, pressure sensors and ADCP. Field test for ONR Asia Seas International Acoustics Experiment (ASIAEX) has been planned in the East and South China Seas in April 2000 and 2001. More than six research ships with scientists from the US and China will participate in this experiment. Dr. Antony Liu has actively participated in the field test planning and coordinates the joint efforts between participants from the US and China.

RESULTS

The Kuroshio moving north from Philippine Basin branches out near the south tip of Taiwan. A part of the Kuroshio intrudes into the South China Sea through the Bashi Channel and the Luzon Strait. The internal tides and internal waves have been generated from the shallow ridges in the Luzon Strait. Surface signature pattern of huge internal soliton packets has been observed in the ERS-1 and RADARSAT SAR images. The crest of soliton is more than 200 km long and each packet contains more than ten rank-ordered solitons with a packet width of 25 km. These are the biggest internal waves that have been observed in this area. The internal wave amplitude is larger than 100 m with surface rips of 1 km wide, based on the observations and CTD casts from Taiwan's research ship during their South China Sea expedition. These huge wave packets propagate and evolve into the South China Sea and finally reach the continental shelf of southern China.

In the northeast of Taiwan, the generation of both depression and elevation internal waves by upwelling caused by Kuroshio intrusion on the shelf under different mixed layer conditions has been demonstrated by numerical simulations (Hsu et al., 1999). In the Yellow Sea, the interaction of nonlinear internal wave packets shows the merging of solitons to a larger single wave packet. The wave-wave interaction observed from the satellite has been studied to interpret the ship measurements from ONR shallow water acoustics experiment in August 1996. The internal wave distribution maps for the East and South China Seas and Yellow Sea are the most recent and important information for future planning of internal wave related field tests.

During the South China Sea Monsoon Experiment (SCSMEX) in May 1998, many SAR images have been collected in near real-time. Based on the RADARSAT ScanSAR images (500 km * 500 km) collected on April, 26 and May 4, 1998, huge internal solitons were observed near Dong-Sha Island with crest more than 200 km long and wave speed of 1.9 m/s (Hsu and Liu, 1999). Most interesting process is the observation of elevation internal waves in shallow water (220 m) and depression waves on the shelf break (500 m) in the same SAR image (5/4/98). The effects of water depth on the evolution of solitons and wave packets have been modeled by KdV-type equation and linked to the satellite observations. For a case of depression waves in the deep water, the solitons first disintegrate into dispersive wave trains and then evolve to a packet of elevation waves in the shallow water area after they pass through a "critical depth" as demonstrated by numerical model (Liu et al., 1998). Based on the numerical simulations, the evolution time for conversion is about 20 hours, and the wave propagation distance can be as far as 200 km which are consistent with the SAR observations. Based on CDT casts during SCSMEX, the mixed layer depth is about 100-150 m, which is also consistent with the prediction from SAR observation of elevation internal waves. Also, in the ScanSAR image near Dong-Sha Island, the westward propagating huge internal solitons are often encountered and broken by the coral reefs on the shelf. In some cases, the broken wave crests will re-merge after passing the island and interact with each other with a phase shift.

Taking the opportunity of Taiwan's research ship R/V-1 for SCSMEX service, Dr. Liu and Professor Tang of NTU put together a test plan of internal wave measurements with ADCP mooring and thermistor chain in April 1999. The location of mooring deployed by R/V-1 on April 9, 1999 for 10 days is at northeast of Dong-Sha Island on the shelf break in 425 m water depth. Based on CTD data, the mixed layer was well defined with a depth of 80 m on April 9 and the background current is barotropic with an average speed of 50 cm/s in the west direction. However, on April 18, the mixed layer was diffused with almost linear temperature profile which is most likely caused by internal wave induced local mixing or breaking. The current profile is baroclinic indicating the passage of a mode-one internal wave. By adjusting the background current, the zero-crossing of internal wave-induced current was about 150 m and it corresponds to the mixed layer depth on April 18, 1999. The ADCP data from mooring show mode-one internal solitons from April 15 to 18, 1999 induced by the semi-diurnal tides. The maximum current in the mixed layer was about 2 m/s in the west direction, and was more than 1 m/s in the east direction in the bottom layer which is typically induced by mode-one waves.

The most surprised phenomenon is the mode-two solitons observed on April 10, 1999 at 11:00AM. The thermistor chain data from April 10 show the mode-two internal waves with negative temperature fluctuation in the mixed layer and positive value in the bottom layer. The mode-two waves are lagging behind the diurnal tide by about 4-hours since mode-two waves have slower wave speed than mode-one waves. The ADCP data from mooring also confirm the mode-two internal solitons on April 10, 1999 with two-zero crossings in current profile and are consistent with the thermistor chain data. The mixed layer depth was about 110m (zero-crossing in temperature) from thermistor, and ADCP shows a mixed layer depth of 120m (maximum current). The maximum current induced by these mode-wave was over 1 m/s. The generation of these mode-two waves is most likely due to the intrusion of seasonal thermocline at the shelf break.

IMPACT/APPLICATION

It is clear that these internal wave observations at northeast of Taiwan in the East China Sea, in the South China Seas, and in the Yellow Sea provide a unique resource for addressing a wide range of processes (Liu et al., 1996). These processes are listed as follows: the generation of elevation internal waves by upwelling, the evolution of nonlinear depression waves through the critical depth, the disintegration of solitons into internal wave packets, internal wave breaking induced by solitons, the generation of mode-two internal waves, and internal wave-wave interaction. The inclusion of these physical processes is essential to improve quantitative understanding of the coastal dynamics. The effects of internal wave on acoustic propagation is a very important issue as demonstrated in the Yellow Sea Acoustic Experiment carried out in August, 1996. The ASIAEX will be conducted in the

East and South China Seas starting in year 2000. One of the major tasks is to study the effects of large-amplitude internal wave packets on the propagation and scattering of sound.

TRANSITIONS

Dr. Antony Liu has collected many SAR images in the Yellow Sea to help the field test planning of ONR acoustics study in the Yellow Sea in August 1996. Their internal wave evolution model has been used in a NRL/SSC study of internal wave effect on acoustic propagation. Recently, the internal wave distribution maps from more than three hundreds of ERS-1/2, RADARSAT and Space Shuttle SAR images in the East and South China Seas and Yellow Sea from 1993 to 1998 have been compiled. These internal wave distribution maps are the most recent and important information for future planning of internal wave related field tests. The ONR ASIAEX will be conducted in the East and South China Seas starting in April 2000 and 2001. Dr. Antony Liu has actively participated in the field test planning and coordinates the joint efforts between participants from the US and China. One of the major issues is the effects of internal solitons on the propagation of sound. It is clear that these internal wave observations in the South China Seas provide a unique resource for addressing a wide range of processes.

RELATED PROJECTS

Dr. Antony Liu has been approved by NASA to take a sabbatical for six months (January to June 2000) at Taiwan and has established an internal wave project with the National Taiwan Ocean University as a part of KUDEX program. Regularly scheduled hydrographic surveys by Taiwan's research ship with CTD casts, thermistor chains, acoustic echo sounder and moored ADCP will be conducted by Prof. David Tang and Joe Wang of the Institute of Oceanography of the National Taiwan University and Prof. Ming-Kuang Hsu of the National Taiwan Ocean University. Dr. Liu and his collaborators in Taiwan will participate in the field test ASIAEX and involve in the future internal wave field studies both in the East and South China Seas. The ERS-2 and Radarsat SAR data will be collected and processed in near real-time at the Taiwan ground station. These in-situ stratification and current measurements will provide a calibration on SAR observations and an input for the numerical simulation of wave evolution on the continental shelf.

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